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ABSTRACT

When new educational technology is put into actual use, new ways of using the technology and new ways of organizing instruction can emerge. A critical feature of formative research conducted in actual settings is that the organization of instruction can change as the educational environment appropriates the technology to its own goals. Thus, the task of design goes beyond the design of the technology to consider how the new goals can enter the technology-environment system. The formative experiment is a method by which changes in goals and uses that occur when a new piece of technology becomes part of an educational environment can be tracked. The theoretical basis for this method is appropriation, in which the teacher appropriates the students' actions into her own way of understanding the task, finds a way for students to play at least a minimal role in its accomplishment, and gives feedback in terms of the expert understanding of the task. Specific examples illustrating the method's application include a Local Area Network environment designed for collaborative school work and intelligent instructional systems for use in training specific technical tasks. (34 references) (GL)

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# Formative Experiments on Technologies that Change the Organization of Instruction[1]

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When new educational technology is put into actual use, new ways of using the technology and new ways of organizing instruction can emerge. This may create problems for standard evaluation techniques but at the same time it may present interesting opportunities for the designers. Levin & Kareev (1980) report a delightful case in which two young boys appropriated the computer-running-a-space-game into their fantasy play, pretending it was the console of their space ship and they were space explorers who would investigate a planet (room of the house) then return to the console to transport them to another planet. How a new piece of educational technology gets used in a particular environment cannot always be anticipated ahead of time. It can be argued that what the environment does with the technology provides critical information to guide the design process.

A critical feature of formative research conducted in actual settings is that the organization of instruction can change as the educational environment appropriates the technology to its own goals. Thus the task of design goes beyond the design of the technology to consider how *new goals* can enter the technology-environment system. For example, goals associated with the workplace can enter the educational environment as the organization of instruction begins to resemble an apprenticeship. Consequently, it is not always possible to specify the objectives of a piece of educational technology and expect them to remain the same once the technology enters the educational environment. If the system falls into disuse or is used for an entirely different purpose, we know radical redesign is needed. But, more likely, the system finds a niche serving possibly multiple purposes that need to be understood in future iterations of design.

This paper describes a set of examples illustrating the ways that the environment changes, sometimes unexpectedly, as a result of a piece of technology being used. I will start by outlining the method called a formative experiment and the theoretical approach on which it is based. The examples include a LAN environment designed for collaborative school work and intelligent instructional systems for use in training specific technical tasks.

## *Appropriation* as a Theoretical Basis for Formative Experiments

Recent work in the cognitive science that is examining thinking and learning outside of laboratory or school settings (Hutchins, in press; Lave, 1988; Newman, Griffin & Cole, in press; Resnick, 1987) has kindled an interest in the developmental theories of Vygotsky (1978, 1986), Bruner (1966) and others who have attempted to integrate the internal developmental processes with the cultural artifacts and social processes outside the individual (Laboratory of Comparative Human Cognition, 1983; Rogoff & Lave, 1984).

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Human cognitive processes involve tools for thinking such as writing or computers that have their own historical development. These may be internalized as with our knowledge of language or remain external, as with our use of computers. These amplifiers of cognition can reorganize and extend human activities making the functional system that includes the people and the tools more powerful than before (Cole & Griffin, 1980; Pea, 1985).

The *interpersonal* cognitive system is important for understanding cognitive change both because of the critical role of culturally elaborated tools and because the activities in which the tools function can be conveyed only through apprenticeship. For example, Vygotsky (1978, 1986) introduced the concept of a zone of proximal development (ZPD) in which children, with help from others, can work at problems that are beyond their competence as individuals. The knowledge and skills that become internalized, in this view, are the interactive processes by which the problem had been worked on.

Newman, Griffin & Cole (in press) introduce the concept of *appropriation* as a descriptive construct for a range of interactions between two parties that have different interpretations of the initial zone of proximal development. They describe teaching and tutorial sessions in which the teacher appropriates the students actions into her own way of understanding the task. The teacher has to find some way for the students to play at least a minimal role in the accomplishment of the task and give feedback in terms of the expert understanding of the task: what the goal is, what is relevant, why his move was not optimal and so on. All the student has to do is produce some move that in some way contributes (or can be understood as an attempt to contribute) to the task. Seeing how his or her action is appropriated provides the student with an analysis of task as the teacher understands it. The basis for appropriation is the notion that human action is essentially a matter of interpretation (Newman & Bruce, 1986) in which plans and goals are strategic fictions that help organize our work together (Suchman, 1987) and the meaning of an action can be changed retrospectively by the actions of others that follow it (Fox, 1987). Appropriation illustrates the essentially interpretive nature of interactions within the ZPD.

The ZPD concept is often used in the context of tests of cognitive ability in which the amount of help the subject needs to reach a criterion performance provides the measure. The use of a static end point, however, while a necessary part of testing, is not inherent in the ZPD theory (Campione, Brown, Ferrara, & Bryant, 1984). In studying the process of cognitive change through observations of the ZPD interactions, it is equally as important to understand where the learners can get given a certain amount of help. Not all learners will get as far or go in the same direction--many end points are possible since th learner is also an active appropriator of the tools the teacher provides (Leont'ev, 1981). That is, learners make use of the culture's tools in their understanding of their own task thus reorganizing and amplifying their own capacities.

The concept of appropriation applies also to the educational environment's adoption of technology. A tool that is appropriated into existing activities can serve as an *amplifier* of those activities. As Cole & Griffin (1980) argue, amplifiers must be understood in terms of the organization of the activity, not just in terms of individual capabilities. Written language, for example, may have specific cognitive effects (Scribner & Cole, 1981) but it also has effects on the way human interactions are mediated (Latour, 1986). Computers amplify a teacher's capacity for a variety of kinds of instruction not by changing the teacher, but by changing the instructional activity from, for example, one in which the teacher presents a book-based lesson to one in which students work at a simulation in small groups. The teacher's goal of conveying an understanding of some physical system is more efficiently achieved and her powers can be considered to be amplified, but the amplification is achieved through a change in the organization of instruction.

An "intelligent" tool can also appropriate the actions of an inexperienced worker or student. For example, a system that provides a trace of the student's algebra problem-solving activities in effect takes the students actions and displays them in a framework that the student may not initially understand. By seeing how his or her actions are displayed, the student can come to understand, for example, that problem-solving is a process of successive attempts and backtracking. Teachers can appropriate an intelligent instructional system into their own lessons and classroom activities (although in this case we would not expect any cognitive change in the system as a result of its being appropriated.) Any tool can be appropriated by people's activities and thereby come to play a role somewhat different from that of the original designers of the tool. Just as students need not initially understand the teacher's task to which their actions are appropriated, a designer of educational technology need not entirely understand the educational environment to learn something about the environment and the technology by seeing how the environment appropriates the technology.

Formative experiments track the changes in goals and uses that occur when a piece of technology becomes a part of a new educational environment: how does the technology get used or understood differently from the original assumptions of the designers? How does the technology present new interpretations and ways of approaching the work not initially available in the environment? Formative research generally has the goal of improving the design of some product (TV show, software, curriculum materials) by having people use it. In formative research, the researcher sets a pedagogical goal and finds out what it takes in terms of materials, organization, or changes in the technology to reach the goal. Instead of rigidly controlling the treatments and observing differences in the outcome, as in a conventional experiment, formative experiments aim at a particular outcome and observe the process by which the goal is achieved (P. Griffin, personal communication). This format is commonly used in formative evaluation of software (Hawkins & Kurland, 1987) where the designer iteratively improves the product until it is successful in terms of appeal, effectiveness, etc. Typically users are put in front of the prototype product for a few minutes to an hour in order to get feedback for the next stage of production. The experiments we have been conducting have a similar motivation but involve a much longer time frame and greater involvement in the context of use than is typically found in formative testing. In contrast, instructional technology systems that involve teachers as well as students can be tested only by being put into use in actual instruction. This often involves elaborate arrangements including teacher training, curriculum development, and production of classroom materials in order to create the environment in which students and teachers can confront real instructional tasks. It is seldom the case that the technology can be inserted into a classroom without changing other aspects of the environment.

Often the impact of a formative experiment is found in new ways of teaching, different relationships between teachers and students, and new topics being taken up. The outcomes of these experiments go beyond what can be captured by the usual interview data or set coding scheme. The changes, especially when they impact the social organization, may require the experienced eye of the ethnographer as well as psychological observations and an understanding of the technology. What is of interest is the ways that people go beyond what was specifically designed for. Findings concerning where the people take the technology, how they appropriate it to their own goals, and how they change what or how they teach or learn provide the basis for designing the next version of the technology so as to provide specific support for these new ways of working.

## A LAN Environment for Collaborative School Work

For the last three years, the Earth Lab project has been designing and observing the effects of a local area network (LAN) system intended to facilitate collaborative work in elementary school earth science. The pedagogical rationale was that students should use technology the way real scientists do: to communicate and share data, i.e., to collaborate. In this project we were using educational technology specifically to change the educational environment from one that discouraged collaborative work among students to one in which collaborative work was used routinely. While we were moderately successful in this attempt, both the teachers and the students used the system in unanticipated ways.

Our plan was to create a prototype LAN system and demonstrate it in a public school using an earth science curriculum. A year-long formative experiment was completed in June, 1987. A LAN connected the 25 Apple IIe computers in the school to a hard drive which allowed for central storage of data, text, and programs. The Bank Street Writer word processing program was enhanced with an electronic mail system. The Bank Street Filer was another basic tool which made it possible for students to create databases which could be accessed from any computer in the school (Newman & Goldman, 1987).

The electronic mail system opened up new channels for communication (Goldman & Newman, 1988; Newman, 1987). Students communicated with their teachers in ways other than through the discourse of the classroom lesson. Students communicated with other students both within their class and outside the school. Small groups of students collaborated to answer questions that the teacher sent after the lesson. Science activities were devised in which small groups invented questions for other groups to answer and these questions and answers were exchanged using the mail system.

Databases were shared among different groups in the class and were also created by groups and individuals for many different purposes. During the lunch hour, students invented databases of their favorite action figures. In social studies, students researched almanacs and other sources to fill in databases about countries of the world, and figures from Black history. In science, they examined databases of dinosaur fossils and earthquakes and created a database of the weather readings that small groups of students collected over a 3 month period. These activities were successful in large part because the computers were networked. Clearly, the electronic mail system was dependent on the connections among the computers. The database activities were also dependent on the connections since students shared different data with different students or groups in the school. A student may have data she shares with a science group, with a noon hour club, and with the whole class. It would not have been possible for each student to have her data on a floppy disk since the social organization of the data access required that multiple routes be possible into school's database. Management of the data organized by groups and individuals was the role of the network interface we designed.

The network interface program was designed to make it easy for individuals or small groups to store and retrieve data pertaining to their projects. Students and teachers identified by their homeroom class and a name could be assigned to any number of workspaces. Each workspace had a name which sometimes referred to the kind of work or activity for which it was used and sometimes was a distinctive name for a group of students who used the workspace. For example, workspaces with names like FRED.MARI were set up for pairs of students to work on writing assignments together. Other workspaces served clubs like YOUNG.ASTRONAUT. Each individual also had a personal workspace having the same name as his or her login name, such as FRED, MR.RHODES and so on. The science teacher, who had the students for two periods a week had the class form into

groups of three or four for the purpose of conducting investigations in the science lab. The science groups gave themselves names such as STAR.WARS or PETITE.FOUR. These names later were made into group workspaces on the network.

Over the year, there was substantial movement toward more small group work. Teachers accepted fewer copies of the classroom materials since they realized that one copy was sufficient for a group. One classroom teacher for the first time conducted an activity with each small group in turn leaving the rest of the class to do seat work on their own. Another teacher led several class discussions on how working in small groups was different than working alone or with the entire class. We found the science groups which originated in the science lab being used by the classroom teachers for a variety of social studies research activities, some of which were unrelated to the earth science curriculum. The network system produced these changes in an unexpected way: it made it possible for all teachers to assign classroom work to the science groups. The science group workspaces were a convenient means for organizing small group projects in other curriculum areas.

The classroom teachers were not entirely happy with the science groups since they would not have put those sets of students together, especially since the groups were all single-sex. Because our network interface system lacked an easy-to-use management utility, it was not straightforward to modify the groups or to easily create new groups. This was a source of frustration for the teachers who would have liked to reassign some of the students or even create new sets for other purposes. These inconveniences help to accentuate the fact that the science groups had become a resource across the school. Never had there been a mechanism by which a social organizational structure created by one teacher in this school could be used by other teachers as a resource for managing instruction.

The students also found unanticipated ways of using Earth Lab. Computers in the classrooms and in a central computer lab were all networked. We expected that projects would be started while the class was in the computer lab and would be continued in the classroom. We found the students were taking this flexibility another logical step. We observed two students working together at a classroom computer on individual book reports. They had not finished when it was their class's turn to go to the computer lab. Instead of dropping their work, they brought their notes with them and asked if they could continue their work at a lab computer while the rest of the class worked on other assignments. The students logged on and called up the file on which they had been working. The boundaries between one class period and another became permeable. This permeability was used by the students to pursue their own tasks.

Many students used the system extensively for their own work in addition to the work assigned as part of instruction. Students developed a sense of ownership to a greater extent than we anticipated. Some students accumulated hundreds of files in their personal workspaces over the course of the year. Earth Lab was also used for student-initiated collaborative work although it was not particularly well designed to facilitate it. In a year-end interview, we asked students to suggest improvements. One student, Mari, said she would like to create a new workspace to which she could give other students access. She explained that she often works with Alissa and they have to either work in her or Alissa's personal workspace. When one of them is absent, the other could not get at the work. This kind of user-creatable workspaces is a common feature of fileservers but had not been implemented on the Earth Lab system. For Mari, who had no familiarity with other fileservers, the idea was an invention based on a need that arose in her own attempts at collaboration. Common to these observations is the perception that students had a place in the computer system, namely, their individual and group workspaces containing their

project data, that was not dependent on having an individual computer. Both students and teachers made use of the workspaces to bridge between school contexts. The extent to which both teachers and students appropriated the system into their own work gives us reason to believe that systems like Earth Lab are sustainable in the educational environment. The system that we installed in the school was to some extent modelled on the use of technology in research labs but the system that emerged had characteristics quite specific to schools, e.g., the coordination of small groups, the teacher collaboration and the use of workspaces rather than personal workstations.

## Using Intelligent Instructional Systems in Real Contexts

Intelligent instructional systems we are currently developing and testing provide additional examples of how technology can change the organization of instruction in the educational environment. The two systems were designed to play a role in an army training school. In both cases a well-specified program of instruction was already in place in which instruction was divided between lecture presentation and practical exercises using conventional simulators and real equipment. Of interest is how this environment was modified with the introduction of the systems and the implications of these changes for the use of intelligent systems in real instructional environments. Unlike Earth Lab, the development of these systems did not have the explicit goal of changing the environment. Nevertheless, interesting changes occurred when the systems were put into use.

The intelligent instructional systems (IIS) we are working with are not conventional intelligent *tutoring* systems (ITS) since they do not contain an explicit model of the instructor or a model of the instructors model of the student. They do contain a simulation of an operational system and a model of expert performance on the task that is the basis for intelligent feedback. They are meant to play a role in instruction as conducted by human instructors, hence the term IIS.

The first example is an IIS to train mechanics to repair a complex radar (Kurland & Tenney, 1988). Mechanics use two sets of esoteric documents: a set of schematics and a book of fault isolation procedures (FIP). Having little background in the advanced electronics involved, the trainees are walked through the schematics in lectures and then attempt to follow the complex branching in the FIP during practical exercises. There is little opportunity to apply a theoretical understanding of how the radar works to the task of troubleshooting and graduates of the program have little understanding of the principles (Tenney & Kurland, 1988). The IIS, called MACH-III, consists of a simulation of the radar represented in color as an animated schematics and with the physical locations of all the parts represented spatially. If one component is broken, e.g., a wire is shorted, the simulation can indicate the change in information flow throughout the rest of the system. A second screen provides text information such as explanations, feedback, and guidance. Problems can be set for the student and a troubleshooting "expert" is available to provide critique and advice and/or display the troubleshooting steps, based on the FIP, in a tree diagram.

The initial formative research involved sitting pairs of students down at the system and having them troubleshoot simple problems. Besides the usual information about understandability, interface ease of use, etc. we were interested in how the students tackled the problem, for example, whether they would make use of the "expert", whether they would continue to consult their reference manuals, etc. We also sought advice from the instructors about how to organize the use of MACH-III. An issue that came up repeatedly from both instructors and students was a concern about the IIS turning into a crutch. It is not enough to learn to troubleshoot using the simulation, it is also necessary to learn to use the schematics and FIP. The IIS will be left at the school but the paper documents are the

basic tool of the trade and are referred to even by very experienced mechanics in doing their work.

An evaluation study of MACH-III served also as a formative experiment on its use in actual instruction (Kurland, 1989a; 1989b). The IIS is viewed both as a link between the lectures and the practical exercises (PE) and as a mediator between the students understanding of the radar and their understanding of the paper documents. Both lecturers and PE instructors were given instruction on the use of the IIS. In addition, lecturers used color overheads in their classes which show various views of the radar as modelled by the simulation. Thus, the lectures are showing the link between the highly abstract schematics and MACH-III's more physically oriented representations of the same circuits. In the PE portion of instruction where the IIS is located, students continue to use their schematics and FIPs while working with the IIS. The "expert" refers to the FIP when suggesting a particular step. Observations during the experiment indicated that instructors specifically reinforced the use of the documents during MACH-III practice.

The importance of the paper documents as a tool of the trade was not clear in the task analysis until the IIS with its "expert" alternative to consulting the documents was actually introduced and students and instructors were able to react to it. The goal of instruction defined narrowly as an understanding of the radar or the ability to troubleshoot was broadened to include a relationship to the documents which would be critical after the students left school. The role of MACH-III as a mediator rather than as an instructor emerged to deal with the need to provide tools for use in the field. The formative experiment considers how the program of instruction as a whole--including lectures, conventional PE and simulated troubleshooting--becomes more integrated and how the existence of the IIS changes the students' relation to the paper documents.

A second IIS trains students to operate an automated missile system (Newman, Grignetti, Gross & Massey, in press). A component of the existing program of instruction for this system was concerned with understanding its automatic operation using a conventional simulator. The usual task was to run the simulator in manual mode and get the student to mimic the automatic operation on the assumption that if they can do manually what the system does automatically, they will understand the automatic operation. The IIS, called INCOFT, provides a simulator of the system as well as feedback and "expert" demonstrations on the basis of an articulate simulation of the automatic operation which could be compared with the students performance. Feedback in the form of comments on each action (in comparison to what the system would have done) and a summary table listing all the actions listed not chronologically but clustered by each case the student was dealing with during a scenario.

As with MACH-III, INCOFT forms a bridge between the lectures and the practical exercises. Since INCOFT provides feedback on each action, it is possible to present subtle cases which illustrate specific problems covered in the lecture. Without the feedback there is no way of assuring that the student noticed the features of the case that are important for instruction. Also, since the IIS can articulate the "expert" process for any specific case in a scenario, it can serve as a vehicle for reviewing specific lecture material. The system feedback also cuts across the standard division of labor of the two system operators which is used as the basis for the sequence of lectures and practical exercises, i.e., first the students learn the officer's job and then they learn the assistant's job. From the system perspective, however, the division of labor is somewhat arbitrary and the IIS feedback concerning performance in one job is presented in terms of how it will impact the other job. This form of feedback becomes an opportunity for the instructors to point out the interdependence of the two jobs.

As became clear in a formative experiment involving two instructors and four students, the instructor-student interaction with INCOFT is very different from that with the conventional simulator. In the conventional case, the instructors' role consists of walking students through some initial scenarios and then watching over the shoulder of students who are having trouble. With INCOFT, the instructor discusses the IIS feedback with the student, pointing out weaknesses and suggesting review and "expert" demos. Instead of providing feedback directly, the instructor is in the role of interpreting the feedback from the system. The cognition involved in providing feedback to the student is now distributed between the teacher and the technology (Newman, 1989). Given the changing role of the instructor in relation to the technology we are considering tools which will support the new forms of interaction. Our interest focuses on how the IIS changes the goals for practical exercise, moving it more toward an integration of the information covered in lecture and toward considering the rationale for the system operation which is currently covered in on-the-job training if at all.

The two cases of IISs considered here are "schoolhouse" trainers used in formal instruction before on-the-job work begins. In both cases, however, students are expected to continue their training on-the-job so what happens in the school is obviously linked to the goals of the actual work. The goals of the school were quite modest and the graduates were far from fully competent. A change we might expect with IIS technology is the movement of more of the training into the school, producing more competent graduates. However, another possibility is that the IIS technology may find a more important role on-the-job as intelligent job aids that provide support and instruction for novice operators or mechanics. Such technology would support an apprenticeship allowing novices to gradually assume greater responsibility. But this would be a very different educational environment from the school. The advantages of learning in a meaningful context may support the migration of IISs into the workplace.

## Conclusions

The cases described in this paper illustrate changes in the educational environment that go beyond the initial objectives. While we may consider ourselves engineers of the educational environment, we are never in full control, we seldom know what the environment is capable of given new tools, and we cannot always see how factors currently outside the environment can introduce new goals. This is the peculiar feature of formative experiments involving use of the new technology in actual settings: as designers of the environment, our own goals change as we see the technology appropriated in new ways.

Narrow definition of educational objectives in terms of test scores and the current classroom curriculum is attractive to administrators who must show quantifiable improvements. Applying educational technology to goals so defined may not be the best approach ultimately since educational tasks with a meaningful relationship to the world outside the classroom may in the long run produce more useful knowledge and skills. It may also blind us to the ways that the environment takes the technology beyond the initial goals that we set based on the current educational environment. We cannot hold to a simple technological determinism that suggests that the environment will be controlled by the introduction of new technology. Very likely the technology will have an effect but it is an important empirical issue as to what the effect is and how it is achieved.

Our formative experiments suggest that an evolution toward a different educational environment is possible. Educational environments of the future may look very different from the schools of today. Advanced technology can increase the initiative of both students and teachers. Both parties in the environment can have a hand in appropriating the

technology to goals that they define and in helping to evolve the goals of the environment so that they more adequately reflect the needs of a changing world.

Three possible directions for the evolution of technologies appear, at this time, worthy of continuing investigation: integration of school and work, collaborative learning, and the use of technology for what Collins & Brown (1987) call a "tool for reflection".

Technology can present educational tasks that are more meaningful by virtue of their connections to real world data and tasks. It can open up channels of communication that allow new goals from the educational environment's context, such as the work environment, can be drawn in. For example, we find in an Earth Lab classroom that the teacher uses the networked database for keeping track of lunch money and students assist in this work context using the same database facility that they use in their science and social studies investigations. As with intelligent job aids that serve an apprenticeship function, the technology may increasingly merge education and work.

Collaborative learning using advanced technologies is likely to be a major feature of future educational environments not only because technology will continue to be a limited resource but, more importantly, because many educators consider collaborative learning to be educationally sound (Educational Researcher Editors, 1985). Even from a purely practical point of view, it is often useful to have two minds engaged collaboratively in interpreting the complex display of information provided by the technology. Having more than one student at the computer may appear to be a problem for the design of conventional intelligent tutoring systems since the student model is usually assumed to be a model of the individual. It may be that the social environment will lead to a redesign of the technology. Or it may be the case that a student model can apply as well to a group as an individual. This is an area for potentially interesting interactions between forces in the environment and technology design.

A third suggestion for how technology might coevolve is that instead of serving as a tutor, the ITS might become a tool that students use to learn with. Collins & Brown (1987) have discussed the potential for technology to show students a trace of their own problem-solving processes and thus serve as a tool for reflection. The trace can also be used to deepen and enliven student-student and teacher-student interaction by providing a common object of conversation. From this perspective, a "student model" is also a trace of student performance as interpreted by the ITS. Ridgway (1988) suggests that ITSs that can describe their own processes in coming to conclusions about students might turn out to be very useful as a tool for students' reflection on the learning process. As Ridgway suggests, ITSs can be designed to be more "transparent" in order to facilitate this method of using them. It will be interesting to see if ITSs begin to be used this way in instructional contexts.

An evaluation process for educational technology that watches for cases where the environment takes the technology beyond the designers' initial assumptions can help to guide a process of evolution toward more effective education. This paper has provided some current examples and some speculations that illustrate directions these changes may take.

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